Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 34 (2012) 146 – 151

Procedia Engineering

www.elsevier.com/locate/procedia

9th Conference of the International Sports Engineering Association (ISEA)

Effects of surface structure on soccer ball aerodynamics

Firoz Alam, Harun Chowdhury*, Mark Stemmer, Zilong Wang, Jie Yang

School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, VIC 3083, Australia

Accepted 02 March 2012

Abstract

Soccer is the world's most popular and watched game. Due to increasing technological advancement and demand for performance, the ball manufacturers have been progressively introducing new designs since over the last decade. A traditional spherical soccer ball made of 32 stitched leather panels in 1970s has now become 8 synthetic curved thermally bonded panels. Despite being most popular game in the world, limited data is available on aerodynamic behaviour of new soccer balls especially with various surface structures and ridges. The primary objectives of this study were to evaluate aerodynamic performance of six different soccer balls which include an old vintage to current balls. The aerodynamic forces and moments were measured experimentally for a range of wind speeds in the wind tunnel. The aerodynamic forces and their non-dimensional coefficients were determined and compared. The findings indicate that the surface structure has profound effect on the flow regime around balls and their drag coefficients.

Keywords: Soccer ball; aerodynamics; drag; wind tunnel; Fevernova; Teamgeist; Jabulani; Nike T90

1. Introduction

The soccer game is a truly world game with matches being broadcast across the globe to audiences of millions. The centre piece of the game is no doubt the spherical ball. The flight trajectory of the ball largely depends on its aerodynamic characteristics. Depending on aerodynamic behaviour, the ball can be deviated from the anticipated flight path resulting in a curved and unpredictable flight trajectory. Lateral deflection in flight, commonly known as swing or knuckle, is well recognized in cricket, baseball, golf, tennis, volleyball and soccer. Therefore, the aerodynamic properties of a soccer ball can be considered fundamental for understanding the soccer ball's flight trajectory. Although, the soccer ball among all spherical sport balls traditionally has better balance, over the years, the design of soccer balls has

* Corresponding author. Tel.: +61 3 99256103; fax: +61 3 99256108.
E-mail address: harun.chowdhury@rmit.edu.au.

doi:10.1016/j.proeng.2012.04.026

undergone a series of technological changes, in which the ball has been tried to make more spherical by utilizing new design and manufacturing processes. Adidas, the official supplier of soccer balls to FIFA, has applied thermal bonding replacing traditional stitching to make a seamless surface design by using 8 curved panels instead of 32 panels in its 2010 FIFA World Cup ball. The surface structure (texture, grooves, ridges, seams, etc) of the ball has also been altered in the process. Although the aerodynamic behaviour of other sports balls have been studied by Alam et al. [1], Mehta et al. [2] and Smits and Ogg [3], little information is available about the aerodynamic behaviour of new seamless soccer balls except the experiential studies by Alam et al. [4] and Asai and Kamemoto [5]. Studies by Goff and Carre [6] and Barber et al. [7, 10] provided some insights about the effect of surface structure of 32 panels balls however, no such data is available for new generation soccer balls. Therefore, the primary objective of this work is to experimentally study the aerodynamic properties of several soccer balls made of 18, 32, 14, 8 leather and synthetic panels.

Nomenclature

F_D	Aerodynamic drag
C_D	Aerodynamic drag coefficient
Re	Reynolds number
V	Wind velocity
μ	Absolute dynamic viscosity of wind
ρ	Air density
A	Projected frontal area of ball
d	ball diameter

2. Methodology

2.1. Description of soccer balls

Six new balls were selected for this study. They are: (a) 18 panels vintage 1966 world cup (a close replica), (b) 32 panels Fevernova ball, (c) 14 panels Teamgeist II (2006) ball, (d) 14 panels Teamgeist III (2009), (e) 8 panels Jabulani ball (2010), and (f) 32 panels T90 Tracer balls. The Fevernova, Teamgeist and Jabulani balls are made by Adidas and the 32 panels T90 Tracer ball was made by Nike. The Jabulani and Teamgeist balls' panels are thermally bonded whereas the panels of Fevernova and T90 Tracer balls were stitched together. A pictorial view and the surface morphology of all six balls are shown in Figures 1 to 3. The Jabulani ball was introduced during 2010 FIFA World Cup in South Africa, the Teamgeist II ball in 2006 FIFA World Cup in Germany and the Fevernova ball in 2002 FIFA World Cup in Japan and Korea. The Nike T90 was developed by Nike in 2010. It is currently used by several premier league tournaments in Europe and elsewhere and the ball is approved by FIFA.

a) 1966 World Cup replica (18 panels)

Enlarged view of 1966 World Cup replica surface

b) 2002 World Cup replica (32 panels)

Enlarged view of 2002 World Cup Fevernova surface

Fig. 1. Vintage and Adidas Fevernova balls

a) 2006 World Cup replica (14 panels)

Enlarged View of 2006 World Cup Teamgeist II surface

b) 2009 Confederation Cup (14 panels)

Enlarged View of 2009 Confederation Cup Teamgeist III surface

Fig. 2. Adidas Teamgeist 2006 and 2009 balls

a) 2010 World Cup replica (8 panels)

Enlarged view of 2010 World Cup Jabulani surface

b) 2010 Nike T-90 replica (32 panels)

Enlarged view of 2010 Nike T-90 surface

Fig. 3. Adidas 2010 Jabulani and Nike 2010 T-90 balls

2.2. Experimental setup

In order to measure the aerodynamic properties of the soccer balls experimentally, the RMIT Wind Tunnel was used. The tunnel is a closed return circuit wind tunnel with a maximum speed of approximately 150 km/h. The rectangular test section's dimension is 3 m (wide) × 2 m (high) × 9 m (long), and is equipped with a turntable to yaw the model. Each ball was mounted on a six component force sensor (type JR-3) as shown in Figure 4, and purpose made computer software was used to digitize and record all 3 forces (drag, side and lift forces) and 3 moments (yaw, pitch and roll moments) simultaneously. More details about the tunnel can be found in Alam et al. [8]. A strut support was developed to hold the ball on a force sensor in the wind tunnel, and the schematic of experimental setup with a strut support is shown in Figure 4. The aerodynamic effect of the strut support was subtracted from the mount with the ball. The distance between the bottom edge of the ball and the tunnel floor was 300 mm, which is well above the tunnel boundary layer and considered to be out of significant ground effect.

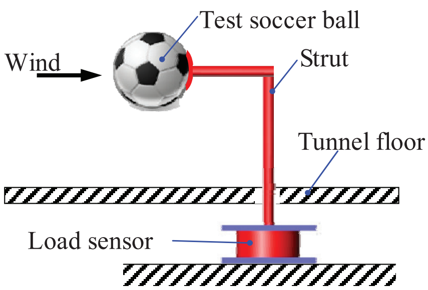

Fig. 4. Schematic of the experimental setup

The aerodynamic drag coefficient (C_D) is defined as: $C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$, where F_D, ρ, V & A are drag, air density, wind velocity and projected frontal area of the ball respectively. The Reynolds number (Re) is defined as: $Re = \frac{\rho V d}{\mu}$. The lift and side forces and their coefficients were not determined and presented in this paper. Only drag data is presented here.

3. Results and Discussion

Each ball as well as a sphere was tested at 5.6 m/s (20 km/h) to 38.9 m/s (140 km/h) with an increment of 2.8 m/s (10 km/h). The aerodynamic drag was converted to non-dimensional parameter (drag coefficient, C_D). The influence of the support on the ball was checked and found to be negligible. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.027 m/s (e.g. 0.1 km/h). The C_D variations with Reynolds numbers for all balls and a stainless steel sphere are shown in Fig 5. The flow transition for the sphere was noted at approximately Re = 1.00E+05 which correlates directly with the published data [9]. The airflow reached critical Reynolds number at approximately 3.00E+05. The critical Reynolds number for the vintage 1966 World Cup replica 18 panels ball occurs at 1.38E+05 at which the drag coefficient is around 0.21. The flow transition from laminar to turbulent occurs between 6.5 and 13.5 m/s (23.4-48.6 km/h). The Adidas Fevernova begins transition shortly before at Re = 1.00+E5 and becomes fully turbulent at 1.38+E5 as the vintage ball. The drag coefficient at the beginning of the transition is about 0.40 while in the turbulent region it is initially 0.16 before rising to 0.19. Transition occurs between 6.7 and 13.5 m/s (24.1 - 48.6 km/h). The critical Reynolds number for Adidas Teamgeist II occurs at about 2.34E+05 at a drag coefficient of 0.16. The drag coefficient is around 0.17 in the fully turbulent flow regime. The Teamgeist III ball which was introduced by Adidas in late 2008 undergoes flow transition between Re = 1.04E+05 and Re = 1.6E+05. The flow transition for Teamgeist III occurs much earlier due to its relatively rough surface compared to Teamgeist II ball. For Jabulani ball, the critical Reynolds number occurs at Re = 1.97E+05 and the flow is fully turbulent after Re = 3.12E+05. The drag coefficient at the beginning of transition is 0.43 and is 0.12 at the completion of transition. The drag coefficient in the turbulent regions continues to increase to a value of about 0.19 at about Re = 4.00E+05. Transition occurs between 9.5 and 14 m/s (33-50.4 km/h). The transition for Nike T90 tracer ball occurs shortly before Re = 8.0E+05 and the flow becomes fully turbulent at Re = 1.96E+05. The drag coefficient at the beginning of transition is observed at 0.41 and begins the turbulent range at C_D = 0.19 before rising steadily. This profile is more synonymous with the drag coefficient profile of a golf ball. Transition is seen to occur at 5.5 m/s and finish just before 21 m/s (54 km/h).

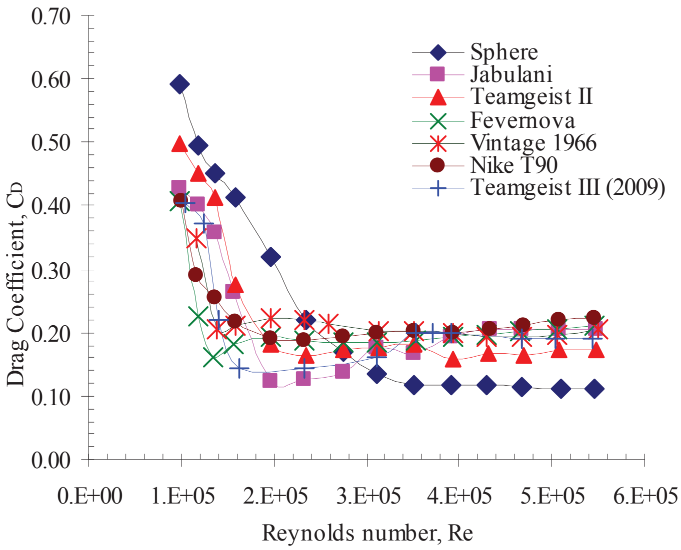

Fig. 5. C_D variation with Reynolds number for all six balls and a sphere

3.1. Effect of surface texture

As the Fevernova and the Nike T90 Tracer have similar panel configurations, it is expected they follow a similar trend. The Fevernova, however, has a much smoother surface yet behaves almost exactly the same as the T90 Tracer. The behaviour of the Fevernova could be attributed to the sharp-seam edges inducing early transition. The T90 Tracer profile is nearly analogous to the C_D profile of a golf ball [6, 9]. The surface texture should have the same effect on the soccer ball as the dimples on a golf ball. The dimples on a golf ball halve the drag coefficient in the turbulent flow region as compared to a golf ball without dimples. The C_D value of the T90 Tracer, however, is identical to the Fevernova in the turbulent region. The surface roughness is believed to be the cause of the increasing drag coefficient in the supercritical and transcritical regions of the Jabulani. In this flow regime, the skin friction drag and pressure (form) drag –both are present. While many of the ridges would correctly orient the flow, other ridges oriented perpendicular to the flow would increase resistance. The ridges of the Jabulani are seemed to be orderly which induced the flow transition at a lower C_D value but at the same time, these same properties increased drag at supercritical and transcritical flow. Study is currently underway to quantify the seam and ridge's geometry and their effects on drag.

3.2. Panel size and seam-length

The size and configuration of the panels revealed elementary information. The vintage ball has 18 panels while the Fevernova and Nike T90 Tracer have 32 yet all three balls encountered transitional flow in approximately the same region. The Jabulani and Teamgeist II - both with significantly less panels and seam lengths - reached transitional flow closer to that of a smooth sphere. There is a correlation between increasing the transition speed and reducing both the magnitude and quantity of surface disturbances. Interestingly, the Nike T90 Tracer reaches transitional flow at a similar Reynolds number to the Jabulani and the Teamgeist II despite having significantly more panels and seam length. Achenbach's findings indicate that transition begins and concludes at lower Reynolds numbers when increasing in fluid velocity [9]. While the Teamgeist II and Jabulani fit this well, the Nike T90 Tracer has a somewhat elongated transition region. Early transition is attributed to the presence of surface roughness however the late critical point is a paradoxical characteristic when contrasted with Achenbach's theory. The roughness could be so finely tuned that transition is slowed, delaying the onset of full turbulent flow.

4. Concluding Remarks

The reduced seam lengths and increasing surface smoothness reduces drag coefficient at high Reynolds number (high speeds). At higher speeds, the Teamgeist II maintains a lower drag coefficient than the Jabulani as it possesses less surface disturbances. Although transitional flow occurred at same velocity for the Fevernova and the Vintage ball, the Fevernova experienced a much lower drag coefficient at transition and throughout the early stages of turbulent flow. The aerodynamic behaviour of Teamgeist III ball is in between Fevernova and Jabulani ball. The addition of surface roughness to the Nike T90 Tracer has caused transition to occur earlier, the turbulent drag coefficient - which is integral to the speed and trajectory of the ball, is no different to the other balls. The Vintage ball performed reasonably well considering the amount of surface disturbance and varying texture of the surface. However, the presence of laces would contribute to potential side force. For the long pass, the Teamgeist II will experience less drag compared to other balls tested. However, the Fevernova and T90 will provide aerodynamic advantage in short passes. The Jabulani and Teamgeist III will provide moderate aerodynamic advantages.

References

[1] Alam F, Subic A, Watkins S, Naser J, Rasul MG. An experimental and computational study of aerodynamic properties of rugby balls. WSEAS Transactions on Fluid Mechanics 2008; 3:279-286.

[2] Mehta RD, Alam F, Subic A. Aerodynamics of tennis balls- a review. Sports Technology 2008;1(1):1-10.

[3] Smits AJ, Ogg S. Golf ball aerodynamics. The Engineering of Sport 5 2004;1:3-12.

[4] Alam F, Chowdhury H, Moria, H, Fuss FK, Khan I, Aldawi F and Subic A. Aerodynamics of contemporary FIFA soccer balls, Procedia Engineering 2011;13:188-193.

[5] Asai T and Kamemoto K. Flow structure of knuckling effect in footballs. Fluids and Structures 2011;27(5-6):727-733.

[6] Goff JE and Carre´ MJ. Soccer ball lift coefficients via trajectory analysis, Eur. J. Phys. 2010;31:775-784.

[7] Barber S, Chin SB and Carré M.J. Sports ball aerodynamics: A numerical study of the erratic motion of soccer balls. Computers & Fluids 2009; 38(6):1091-1100.

[8] Alam F, Zimmer G, Watkins S. Mean and time-varying flow measurements on the surface of a family of idealized road vehicles. Experimental Thermal and Fluid Sciences 2003;27:639-654.

[9] Achenbach E. Experiments on the flow past spheres at very high Reynolds numbers. Journal of Fluid Mechanics 1972;54:565–575.

[10] Barber S, Chin SB and Carré MJ. Sports ball aerodynamics: A numerical study of the erratic motion of soccer balls. Computers & Fluids 2009;38(6):1091-1100.

[11] Oggiano L and Sætran L. Aerodynamics of modern soccer balls. Procedia Engineering 2010;2(2):2473-2479.